Muon-Based Accelerators

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High Energy Physics Planning Committee

Overview

- Types of machines
  - Neutrino Factories
  - Muon Colliders
- Components
  - Target
  - Early transport
  - Cooling
  - Acceleration
- Where are we?

Neutrino Factories

- Give a well-defined, high-flux neutrino beam, with both ν_μ and $\overline{\nu}_e$.
- Two performance characteristics
  - Neutrino flux to detector (primary)
  - Uncertainty in neutrino flux to detector (secondary)
- Neutrino flux directly proportional to muon count
  - Muons approximately proportional to proton beam power
    - Target material has an effect
    - Assumes short proton pulse
  - Both signs, factor of 2! Distinguish by timing
  - Improving efficiency
    - Cooling to increase number of particle that fit in downstream pipe
    - Increase size of downstream pipe

- Improving flux uncertainty
  - Reducing beam size: more cooling
  - Increasing length of storage ring
  - Measuring the neutrino flux
    - ⋆ Exotic near techniques
    - ⋆ Medium-distance detector
- Need to quantify desired flux uncertainty
- Know how to make these. Continued work on cost/performance optimization.

Muon Colliders

- Collide non-composite particles
  - Lower energy for same physics as protons, more compact ring
- Synchrotron radiation/beamstrahlung significantly smaller problem than for electrons
  - Much better energy resolution
- Enhancement of s-channel Higgs cross-section over electrons
- Very high energies ($>$ 3 TeV), neutrino radiation problem!

Target

- Performance of most muon machines proportional to muons produced at target
- Muons produced roughly proportional to proton beam power
- High energy per pulse desirable
  - Lower average power requirements in downstream systems (pulsed RF)
  - Higher luminosity in collider
  - Reach a limit: beam loading
  - Shock stress on target
- High power targets have not fared well, especially with high pulse energies
  - Research program in high power targets
- Important for superbeams, other applications as well

Early Transport

- Muon colliders
  - Put all particles of a given sign in a single bunch: maximize luminosity
  - Requires substantial longitudinal emittance reduction
- Neutrino Factories
  - No advantage to having particles in a single bunch
  - Create long bunch train of smaller bunches
  - Newer schemes keep both muon signs: double performance
  - No longitudinal cooling required

Cooling

- Reduction of beam emittances (sizes), transverse and possibly longitudinal
- Purposes
  - Increase number of muons into fixed-size beam pipe
  - Reduce uncertainty in flux for neutrino beam
  - Increase luminosity in collider
- Must be fast (decay): ionization cooling
- 6-D (longitudinal) cooling
  - Necessary for collider
  - Improves transmission in neutrino factory
  - Reduced energy spread gives lower uncertainty in neutrino factory
  - Cost-effective method: use rings

- ⋆ Injection/extraction a concern
- ⋆ Matching from one stage to the next

- Collider requires much lower emittances than neutrino factory
  - ◆ Very high magnetic fields: lithium lenses
  - ◆ Problems here far from being solved
- Cooling demonstration experiment being built, probably in Europe (RAL)

Acceleration

- Improvements here related mostly to cost reduction
- Novel idea (rediscovery of an old idea): FFAGs
  - Rapid acceleration without ramping magnets
  - Avoids limitations of switchyards in CEBAF-style recirculating accelerators
  - New idea: “non-scaling FFAG”; never been built
    - Would like to build small-scale electron model
  - May be useful for proton acceleration as well
- For neutrino factory, possibly more cost effective to have no cooling and larger aperture in acceleration and storage ring
  - Uncertainty higher

Physics Ring

- Neutrino factory: storage ring
  - Ring must be long, to make large fraction of decays go toward detector
  - Ring must be buried, or create hill
  - Reduce uncertainty by making ring longer
- Muon collider
  - Higgs energy interesting
  - High energies: neutrino radiation
    - Bury ring deep, or raise up high
    - Put in remote location

Where Are We?

- Neutrino Factories
  - We know how to build them
  - Need target design for high performance
  - Still plenty of work to optimize cost/performance
  - Machine requirements for physics must be defined
- Muon colliders
  - Need more work on cooling
    - Longitudinal cooling
    - Cooling to very low emittances
  - Deal with neutrino radiation issue